BONE SCINTIGRAPHY AND THE MANUBRIO-STERNAL JOINT

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BONE SCINTIGRAPHY AND THE MANUBRIO-STERNAL JOINT

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INTRODUCTION AND SUMMARY

The section of nuclear medicine at Yale-New Haven Hospital has noted considerable variability in the appearances of the sternum and manubrio-sternal joint (MSJ) on routine technetium-99m Methylene Diphosphonate (MDP) bone scans.

This variability has at times posed a problem in the clinical interpretation of MDP bone scans in the evaluation of metastatic disease. An improved understanding of the pathophysiologic mechanism that contributes to the bone scan appearance of the MSJ would therefore be of benefit in clinical bone scan interpretation.

This thesis begins with a review of the embryology and anatomy of the sternum with emphasis on the anatomy and pathology of the MSJ. It then introduces a working hypothesis that the degree of visualization of the MSJ on MDP bone scans correlates with the presence of obstructive pulmonary disease. To test this hypothesis, a group of twenty-five patients with "normal" sternums, i.e., sternums whose MDP uptake had not changed in six months or more and who had also undergone recent pulumonary function testing, were examined.

In the final discussion it is concluded that the results of the study lend support to the hypothesis, at a statistically significant level. A secondary benefit is derived in the description of normal variants.

ABBREVIATIONS USED

MSJ	Manubrio-sternal joint
MDP	Technetium-99m Methylene Diphosphonate
T3	Third thoracic vertebrae
T4	Fourth thoracic vertebrae
RA	Rheumatoid arthritis
AS	Ankylosing spondylitis
PFT	Pulmonary function tests
FEV_1	Forced expired volume, 1 second
FVC	Forced vital capacity
TLC	Total lung capacity
RV	Residual volume
COPD	Chronic obstructive pulmonary disease
PA	Posteroranterior
CABG	Coronary Artery Bypass Graft
cm	Centimeter

THE STERNUM

The adult human sternum consists of three parts: the manubrium, the mesosternum (or body) and the xiphiod process. It is approximately seventeen centimeters long in males and is significantly shorter in females (Williams, p. 286). The sternum is convex anteriorly and concave posteriorly; it is inclined anteriorly and caudally.

THE MANUBRIUM

The manubrium usually is situated opposite T3 and T4; it is a broad thick bone whose shape shows considerable variability; it tapers to meet the mesosternum. (See Figure 1.) The smooth anterior surface is convex from side to side and concave from top to bottom and is attached to the pectoralis major and sternocleidomastoid muscles. The concave posterior surface is attached to the sternothyroid muscle and usually the medial aspect of the sternohyoid muscle. The thick superior border contains the central jugular (suprasternal) notch and the bilateral clavicular notches. The lateral aspect joins the first costal cartilage in a synchondrosis. Inferiorly there is a small articular facet which with a similar facet on the body forms a joint with the second costal cartilage. (Williams, pp. 286-287)

THE MESOSTERNUM

The mesosternum is the longest part of the sternum; it is narrower and thinner than the manubrium although, too, its shape is variable. (See Figure 2.) Its anterior surface is inclined anteriorly and superiorly and is notable for (usually three) transverse ridges that mark the lines of fusion of the sternebrae (see DEVELOPMENT). The anterior surface gives attachment to the articular capsules of the sternocostal joints and also serves as the sternal origin of the pectoralis major muscle. The slightly concave posterior surface also is marked by transverse ridges and serves as the origin of the transversus thoracis muscle (sternocostalis muscle) and as attachments of the external intercostal membranes. The superior surface articulates with the manubrium and a transverse groove on the posterior surface marks the position of the manubriosternal joint (MSJ). The inferior surface is continuous with the xiphoid process. The lateral border of the mesosternum contains costal notches in which the third, fourth, fifth and sixth costal cartilages articulate. The lateral surfaces also contain small facets where the second and seventh costal cartilages articulate. (Williams, pp. 286-7)

THE XIPHOID PROCESS

The xiphoid process, lying in the epigastrium, is the smallest and most variable part of the sternum. It may have

a notch or a foramen (Moore, p. 312); it can be broad or thin, pointed, bifid, curved or deflected to one side. (See Figure 3.) In the thirty percent in whom it eventually ossifies, it does not do so until adulthood. The medial fibers of the rectus abdominus, the aponeuroses of the internal oblique and the aponeuroses of the external oblique attach to its anterior surface. The lateral surfaces give attachment to the aponeuroses of the internal oblique and transversus abdominus muscle. Its posterior aspect gives rise to some of the diaphragm's fibers. Superiorly, the xiphisternal joint is a symphysis which usually becomes synostosed by the fortieth year. The xiphoid process, however, can remain separate throughout life. (Williams, pp. 286-7)

BLOOD SUPPLY

The internal mammary artery and its branches provide most - if not all - of the sternum's arterial blood supply. Latero-sternal, retro-articular and retro-sternal arch systems anastomose the postero-superior and postero-inferior sternal arteries of an interspace or of contiguous interspaces. The arch systems give rise to vessels which either go directly to the sternum or form the posterior peripheral sternal network. The anterior sternal branches assume one of three roles. They either form arches, go to the anterior peripheral sternal network, or go directly to the sternum.

The sternal networks are especially developed in the lower mesosternum; the posterior network is generally thought to be more developed with smaller albeit denser loops.

The veins have less anastomoses than the arteries and therefore form less distinct arches. The venous networks, however, are denser and more irregular than the arterial networks. (Arnold, Pismenov, and Sick)

INTRA-SKELETAL COMPOSITION AND VASCULARIZATION

The sternum is composed of red marrow within well vascularized trabecular bone which is covered by a compact layer. Low magnification scanning electron micrographs demonstrate that the medial cancellous bone is tightly constructed while laterally the trabeculae are thicker with larger spaces between them. (Whitehouse)

DEVELOPMENT

The sternum develops from two mesenchymal condensations known as sternal bands or plates which appear at approximately six weeks gestation and an anterior median rudiment which appears slightly later (Currarino). Although the precise origin of the sternal plates is not known (Moore, p. 306), they develop in the dorso-lateral body wall (Fell, Seno, and Williams, p. 141). Experiments in mice (Chen,

1952a, 1952b) and chicks (Seno) have shown that the sternal plates are just ventral to and independent of the rudimentary clavicles and ribs. The plates lengthen caudally, chondrify and move toward each other to eventually fuse in a cranio-caudal direction in the midventral line while incorporating the median element. (See Figure 4.) The clavicles and upper seven pairs of costal cartilages eventually become attached. The xiphoid process then develops as an extension of the sternum. (Williams, p. 141)

OSSIFICATION CENTERS

Cartilage cells in the intercostal regions hypertrophy to become the future ossification centers of the manubrium and the body's usual four sternebrae. A minority of xiphoid processes contain ossification centers (Kozielec). The centers are "endochondral, being embedded in a mass of cartilage which presents, approximately, the shape of the definitive sternum" (Ashley, 1956). The number and arrangement of the ossification centers varies widely and is said to relate to the completeness and time of fusion of the sternal plates as well as the ultimate width of the sternum (Ashley, 1951, 1953, 1956).

The ossification centers are segmentally arranged; within a segment there may be one median center (46%), a pair

of centers (34%) placed laterally, vertically or obliquely, or multiple centers (20%) irregularly arranged (McCormick). The average age at which centers appear is shown in Figure 5.

Ashley (1956) found that there are three basic ossification patterns as well as numerous "irregular" patterns. Descriptions of the basic patterns follow:

I. "In each of the first three segments of the mesosternum the ossification centres are usually single and always mid-line. Occasionally they may be double vertically, but still, strictly mid-line in position. In the fourth segment centre(s) may be single, double or completely absent."

II. "In either the first or first and second segment(s) of the mesosternum the ossification centre(s) is/are single and mid-line, whereas in the second (in some), third (in all) and fourth (in some) the centres are double, and bilaterally or obliquely placed."

III. "In each of the first three segments of the mesosternum the ossification centres are double (bilaterally or obliquely), and in the fourth segment the centre(s) may be double, single or absent." Because of its rarity, also included in this group were sterna with a pair of centers in the first or first and second sternebrae and a single center in the third and a single or absent center in the fourth sternebrae.

These patterns are illustrated in Figure 6.

Childhood ossification patterns persis in 50-60% of adults; the pattern is not discernable in the remainder. Ashley found that the ossification pattern correlated with the shape of the mesosternum. Pattern I sterna developed into narrow mesosternum with parallel sides; pattern II sterna had narrow first sternebrae and wide third sternebrae, and those with pattern III developed into wide mesosterna with parallel sides. These shapes did not correlate with sex or race.

The factors which determine the number and location of the ossification centers and their adjacent sutures as well as the factors that delay the ossification of the suture lines are not well understood. Ashley (1956) argues that the wide variation in the number and location of ossification centers results from "incoordination between (a) the time and completeness of mid-line fusion of the lateral sternal bands, and (b) the times of appearance of the individual ossification centres." He reasons that if the sternal bands have fused completely prior to the start of ossification, the ossification centers will be single and mid-line. If, however, the bands do not fuse or are only partially fused, the ossification centers will be paired.

Numerous others also argue that the location and pattern of ossification is not genetic. Patterson (1904) thought that stress or strain in the cartilaginous sternum

causes vascularization and ossification. Hanson (1919) suggests "that sutures develop in response to stress at certain structurally weak points in the fetal sternum, where this structure is narrowed by the notches normally present at the costosternal junctions."

Bryson (1945) and Chen (1953) believe that the ribs cause formation of the sutures and therefore that the ribs indirectly determine the location of the ossification centers. They theorize that when the ribs and sternum are in intimate contact, the tips of the ribs have a biochemical and/or mechanical effect on the sternum which prevents the spread of chondroblastic proliferation to the sternal cartilage adjacent to the rib tip. This results in immature cartilage that resists ossification.

The number of ossification centers is not related to age (Kozielec, Riach) or sex (Kozielec). The mean size of individual ossification centers does, however, increase with age and correlate with sex - with females having larger ossification centers (Krechowiecki). The total ossified area also correlates with age (Riach) and indeed one can write a valid equiation relating the area of ossification to time (Spencer).

As portrayed schematically in Figure 5 the sternebrae eventually coalesce in a caudal-cephalad direction.

Although closely placed centers may fuse in late fetal or early post-natal life, the portions of the bone derived from each ossification center generally remain independent for many years - until the process of fusion and obliteration of the primary cartilaginous joints separating the sternebrae intervenes. This process is normally complete by 25 years of age. Abnormalities in this process include premature synostosis and reduced segmentation of the sternum which results in a shortened sternum and an abnormally shaped thorax (Fisher, Currarino).

Influences on ossification include sports (Sklad) and congenital heart disease (Andren). Although sternal abnormalities following pediatric midline sternotomy are common, it is not known if sternotomy effects the ossification process (Ogden).

ABNORMALITIES OF PRE-NATAL STERNAL DEVELOPMENT

Several asymetric abnormalities of sternal anatomy occur as the result of pre-natal events. A complete sternal fissure has been described by Magan (1949) and Larson (1962); in this condition a deep cleft separates paired segments of the manubrium, body and xiphoid.

Sternal foramen occur in approximately 7.5% of adults (McCormick) (see Figure 7); they result from a vascu-

lar bundle transversing the cartilaginous sternum. This causes a foramen by not allowing the third and fourth sternebrae to completely fuse (Williams, pp. 287-8) or by preventing ossification centers within a sternebrae to coalesce (Ashley, 1956).

THE MANUBRIO-STERNAL JOINT

ANATOMY

The manubrio-sternal joint (MSJ) is usually a synchondrosis similar in structure to the public symphysis. This amphiarthrodial joint consists of hyaline cartilage covering the articular surfaces of the manubrium and the mesosternum with a disc of fibrocartilage between the two surfaces. The disc's form shows considerable variation. (See Figure 8.)

The central portion of the fibrocartilaginous disc undergoes absorption in approximately thirty percent of adults; in these persons, therefore, the joint resembles a synovial joint. This is reported to be more frequent in women and in the elderly (Francon, 1953). In others the disc may ossify. The manubrium and body are also connected by a fibrous membrane which encloses the bone. (Williams, p. 452)

The two articular surfaces show considerable variation (Candardjis, 1978). (See Figure 9.) These variants only become clinically significant if and/or when they are misinterpreted as pathologic erosions.

PHYSIOLOGY

By allowing a small degree of change in the angle between the manubrium and body and by permitting anter-

oposterior movement of the sternum, the MSJ aids the respiratory effort. During inspiration the ribs move upward and anteriorly. Because of the shortness of the first rib, the upward and anterior displacement of its anterior end is much less than the movement of the succeeding ribs and, therefore, the upper border of the sternum, i.e. the manubrium, is only slightly raised and minimally moved anteriorly. The longer ribs force the body of the sternum to have greater upward movement and much greater forward movement; this results in the bending of the sternum at the MSJ. (Cunningham, p. 341)

The most recent edition of GRAY'S ANATOMY reports a study (the reference to which is incorrect) that demonstrated a two degree change in the angle between the manubrium and body between full inspiration and expiration. This study of sixty two male athletes showed that the angle was 162.7^{o} in full inspiration and 164.7^{o} in full expiration (Williams, pp. 452-53). To this author's knowledge a similar study of patients such as those with COPD who consistently use accessory muscles of respiration has not been undertaken.

FUSION OF THE MANUBRIO-STERNAL JOINT

For centuries anatomists have argued about fusion of the MSJ. Coiter (1573) stated that synostosis of the MSJ "appears at the time at which the cranial sutures begin to be

obliterated" (Ashley, 1954). Crooke (1615) expressed the view generally shared by seventeenth and eighteenth century anatomists (Highmore, Bartholinus, Bidloo, Weitbrecht, Winslow and Monro): the sternum, he wrote, is "not one bone, unless it be in very old men." This statement has been proven wrong in numerous twentieth century publications (Ashley, Trotter, Paterson, Van Gelderan, Candarjis).

Trotter (1934) studied 877 sterna; she classified them as synostosed when after using a "hot water" method for preserving skeletons - a method which removes all ligaments and cartilage - the manubrium and sternum could not be separated. Her results showed 10.5% of sterna to be synostosed; there was no correlation with age and although 16.3% of female sterna were synostosed while only 10.8% of male sterna were synostosed this difference was not statistically significant. (See Table 1.)

In 1954, Ashley (1954) published a comprehensive study of synostosis at the MSJ. He combined the findings of Trotter, Van Gelderen, Passler and Paterson with his study of an additional 228 sterna; his conclusions, therefore, are based upon study of 2,787 sterna. His findings which were not broken down by sex are summarized in Table 2.

The incidence of synostosis is generally 10% in those coming to necropsy between 30 and 79 years of age.

Ashley's (1954) discussion of the mechanism of synostosis has been unchallenged; he hypothesizes that there are two types of synostosis. The first, "matrical" synostosis, occurs when the MSJ remains a primary cartilaginous joint. A primary cartilaginous joint is normally a temporary joint and one in which the cartilage normally ossifies during puberty, adolescence or early adult life; it is the type of joint that exists in the epiphysial joints of long bones and between the first and second mesosternal segments.

Developmentally the concept of a matrical joint is tenable. Normally (Ruge, 1880 and Paterson, 1904) the presternum (rudimentary manubrium) is separated from the meosternum by a fibrous lamina which develops across the cartilaginous sternum; the lamina is the analage of the secondary cartilaginous joint which is normally found between the manubrium and mesosternum. A study of 236 fetal sterna, however, (Paterson, 1904) showed that in only 76.4% of cases did the MSJ have this fibrous lamina. In the remaining 23.6% then, there is no deterent to fusion of the manubrium and body so that when the segments of the body fuse as they generally do there is no reason to suspect that the manubrium and sternum would not fuse.

Indeed, this makes sense when one considers the percentage of MSJs fused as a function of age. (See Table 2.)

Further, Ashley (1954) has shown radiographically that "the appearances of the various stages of fusion between manubrium and mesosternum are strictly comparable to the appearances at corresponding stages in the fusion between first and second mesosternal segments." (See Figure 10.)

Matrical synostosis occurred in 80% of the cases of synostosis under age 60 while it occurred in only 60% of the cases over age 60.

"Cortical" synostosis accounts for the remaining cases of synostosis - that is, 20% of those under age 60 with synostosed joints and 40% of those over 60 with synostosed joints are "victims" of cortical synostosis. In these cases a band of compact bone unites the manubrium and mesosternum but separates the spongy matrix of one from the other.

Although a distinction cannot always be made between them, there are two types of cortical synostosis "normal" and "sclerotic." Normal cortical synostosis occurs when the cortical bone of a healthy manubrium synostoses with the cortical bone of a healthy manubrium. Sclerotic cortical synostosis, however, occurs when, "chronic infection (sic but how common is this now) or arteriosclerosis has led to sclerotic change in the opposing bony surfaces, to degeneration and attrition of the fibrocartilage, and to ultimate loss of movement and synostosis at the joint" (Ashley, 1954).

Since Ashley's work, little original research has concerned itself with fusion of the MSJ.

Cameron and Fornasier (1974) studied the MSJ in 606 routine necropsy specimens. They obtained 0.5cm slices of the sterna and subjected them to fine detail radiography. 44% showed significant irregularity of the joint surfaces; 8% were partially fused (average age 55.5) and 14% were totally fused (average age 60). Fusion did not correlate with sex but if the thoracic or thoracolumbar spine showed disc degeneration and osteophyte formation the MSJ was always abnormal. The reverse did not hold nor was there a relationship between disc degeneration in the lumbar spine and fusion. Interesting in light of the present study is their one sentence statement - presented without data - that "no relationship was found between fusion and respiratory disease."

THE MANUBRIO-STERNAL JOINT IN DISEASE

There have been several radiologic and pathologic studies which looked at the MSJ in patients with rheumatoid arthritis and ankylosing spondylitis (Marie-Strumpell Disease). Grosbois (1981) showed radiographically that those with AS and/or RA were more likely than a control group to exhibit irregularity of the margins of the joint space, greater degrees of osteoporosis and/or condensation, narrow-

ing of the joint space, erosions and vacuole formation. There was no significant difference in the frequency of the severity of these signs between those with AS and those with RA.

ANKYLOSING SPONDYLITIS-RADIOLOGY

In 1951, Solovay and Gardner reviewed the lateral films of the dorsal spine of 580 non-rheumatoid and 57 ankylosing spondylitis patients. Their results are summarized in Table 3.

The nine patients with pathologic changes "showed varying degrees of erosion of the margins of the articulation or of the actual joint surfaces, increased density of the adjacent subarticular bone, or evidence of beginning obliteration of the joint. One case showed marked bone proliferation at the anterior and posterior margins of the joint and calcium deposition and beginning bridging at the lateral margins of the articulation" (Solovay, 753). Because of the nine AS patients with pathologic changes at the MSJ Solovay and Gardner conclude that active disease in the MSJ causes an increased susceptibility to fusion of the MSJ.

Savill (1951) also studied the MSJ in AS and found abnormalities in 72% of 61 cases that he studied radiographically. From observations of the joint in persons with increasing duration of AS, he concluded that there was a

progressive process in the MSJ that destroyed cartilage and the adjacent bony surfaces. Destruction begins, he maintains, with loss of the bony outline of the manubrium and/or body. There is then a period of "creeping erosion." Finally there is beginning of fusion at the periphery which slowly progresses to complete fusion.

Although this scenario appears justifiable, Savill admits that the majority of his patients showed no change over a three year interval. Only three patients showed significant changes: two of sixteen patients whose joints were initially eroded progressed to incomplete fusion and one out of fourteen patients whose joint was normal had an eroded joint three years later.

ANKYLOSING SPONDYLITIS-PATHOLOGY

Four of Savill's patients with erosion at the MSJ underwent biopsy. The most remarkable features were: (1) replacement of fibrocartilage by collagenous fibrous tissue that spread into bone; (2) absence of inflammatory reaction; (3) osteoclastic activity, and (4) zones of sclerosis limiting the areas of erosion. A biopsy of a fused joint showed replacement of cartilage by bone with some remnants of cartilage and zones of collagenous fibrous tissue in the bone interstices.

RHEUMATOID ARTHRITIS-RADIOLOGY

Although RA is a disease of synovial joints, it can affect the MSJ which, as previously stated, resembles a synovial joint in 30% of adults whose fibrocartilaginous disc undergoes absorption.

Laitinen, et al. examined the MSJ of 87 patients with RA and a control group consisting of 23 patients with osteoarthritis and 72 patients without known joint disease with tomography in anteroposterior and lateral projections. Their results are summarized in Table 4.

Laitinen saw fresh erosions with indistinct margins and osteoporosis as well as erosions bordered by calcium "seams." Although they observed only 14 cases of ankylosis, they were able to distinguish 2 types of ankylosis comparable to those described by Ashley, 1954. Some had a homogeneous bone structure such that not even the site of the MSJ could be discerned, while in other cases there were traces of the joint space with irregularities of the adjacent bone, i.e. sclerotic synostosis. One can conclude that the MSJ is indeed affected in RA. Since the observed changes were ordinarily slight, the diagnostic utility, therefore, is small.

RHEUMATOID ARTHRITIS-PATHOLOGY

Kormano (1970) undertook a microradiographic and histologic study to ascertain the nature of the deformities

in the MSJ that were visible radiographically in patients with rheumatoid arthritis and in those without known joint disease. Radiography of the 20 non-rheumatoid subjects (mean age 69) often showed osteophytes and irregularity of the joint surface but no erosions. Eleven cases demonstrated sclerosis and thickening of bone margins.

The radiographs of the eleven rheumatoid arthritis patients, in contrast, showed a sclerotic bridge in four of eleven patients, and complete fusion in one. Erosions were present in six of eleven cases and sclerotic changes were common.

The microradioraph findings are summarized in Table 5.

Histologically, the non-rheumatoid subjects below age 65 showed no marked degenerative changes. The degenerative changes seen in older subjects were first evident in the hyaline cartilage and, indeed, this layer was affected in most of the joints from those over 70 years. The fibrocartilage was often well preserved but in cases of severe degeneration there were patchy areas of degeneration and narrowing. There were no signs of inflammation in the non-rheumatoid joints.

The histology of the rheumatoid joints showed more variation and more signs of inflammation. The ankylotic joint showed no signs of inflammation; two of the remaining

ten joints showed only degenerative changes. Four joints from persons with long histories of RA showed signs of previous inflammation, i.e. eroded bone and fibrous replacement of cartilage and bone. Four joints showed evidence of chronic inflammation with infiltration of the subchondral bone and hyaline cartilage by granulation tissue, giant cells, and mononuclear and polymorphoruclear cells. One case showed active inflammation while another showed fibrous replacement of the joint space.

This study, too, confirms that although the MSJ is a synovial joint in only 30% of persons it is often affected in RA. It is not clear, however, if the joint was synovial in the majority of those with RA of the MSJ.

BONE SCINTIGRAPHY

In contrast to skeletal radiographs radionuclide bone imaging is a sensitive means of detection of osseous pathology. Focally increased uptake of radiopharmaceuticals occurs in areas of increased metabolic activity and/or blood flow; histologically this local increase correlates with immature osteoid in the early stages of mineralization.

Technetium-99m MDP is considered the radionuclide of choice in most institutions. After being administered intravenously, the major fraction is accumulated by bone where it can probably exchange with one or more of the inorganic components of hydroxyapatite $Ca_{10}(PO_4)_6OH_2$. The presence of perfusion is an important determinant of the bone scan image, but once the radionuclide has reached the extracellular fluid of bone the localization of radionuclide is related to the rate of formation and remodeling of bone. Sites of rapid new bone formation would be expected to have large mineral phase surface areas available for exchange and therefore increased uptake of radionuclide on bone scan images (Kirchner).

Tc-99m MDP AND JOINT IMAGING

Tc-99m phosphate complexes have been used to evaluate joint disorders. Increased periarticular uptake is presumably secondary to increases in periarticular perfusion

and rate of bone remodeling secondary to arthritis. Degenerative osteoarthritis is detectable on bone scans because the changes in periarticular bone lead to remodeling and osteophyte formation which is associated with increased radionuclide accumulation. Trauma and several metabolic bone diseases cause increased periarticular radionuclide accumulation. Normal periarticular regions, too, have greater radionuclide accumulation when compared to adjacent bone (Kirchner).

Tc-99m MDP IMAGING AND THE STERNUM

Ono, et. al. (1980) is the sole group to illustrate the variability of the shape of the sternum by bone scan and the variability of Tc-99m MDP uptake by the sternum. (See Figure 16.) Their work, however, failed to deliniate the causes of the varied sternal image. Many of the variant images can, however, be explained by the anatomy and development of the sternum and their normal variants.

The considerable variability in the shape of the manubrium, mesosternum and xiphoid process causes the image of the sternum to vary considerably from patient to patient.

Persistant cartilaginous ossification centers may, because of their lack of hydroxyapatite, appear as cystic areas within the mesosternum or manubrium.

The fusion lines of the sternebrae - which often persist as transverse ridges - may be discernable as linear areas of increased radionuclide uptake.

Sterna with sternal foramen have an area within the mesosternum which is devoid of bone and blood supply. These sterna, therefore, would be expected to have cystic areas within the mesosternum.

Tc-99m MDP UPTAKE AND THE MSJ

There is little literature concerning the image of the MSJ on bone scan. Although Charkes (1973) mentions that the sternoclavicular joint may be seen, he makes no mention of the MSJ. Thrall (1974) states, "the sternomanubrial and sternoclavicular joints may also be seen normally," but does not elaborate.

Since the MSJ is an active joint, i.e. it is not fused, in 90% of the population one would expect it to be visible in these persons for the same reasons that a normal joint is visible.

A MSJ affected by disease would be expected to have increased radionuclide uptake. A MSJ affected by RA, for example, would have increased blood flow in the synovial membrane and peri-articular bone producing increased radionuclide uptake. Persons with chronic RA may have increased

uptake - akin to that seen in osteoarthritis - the uptake being secondary to focal increases in bone production which occur because of the destruction of cartilage and bone.

PRESENT STUDY

The primary purpose of this study is to test the following hypothesis: does visibility of the MSJ on MDP bone scan correlate with obstructive pulmonary disease?

The plausibility of the hypothesis rests on two linked assumptions. The first assumption is that individuals who have COPD and therefore make greater use of the accessory muscles of respiration will have a greater respiratory excursion of sternum and greater movements of the MSJ. The second assumption is that chronically increased joint excursion will lead to a detectable increase in uptake of the radionuclide, perhaps simply because of increased local blood flow.

METHODS

LOCATION OF CASES

A list of all adults who had total body MDP bone scans performed at Yale-New Haven Hospital from August 12, 1981 to June 29, 1982 was compiled from the records of the Department of Diagnostic Imaging.

The following criteria were necessary for inclusion in the study:

1. The patient must have had at least two bone scans at least six months apart.

2. The image of the sternum on the two bone scans must have been free of definite metastatic lesions and must not have changed in the interim period.

3. The patient must have had a chest radiograph with six months of the date of either bone scan.

4. The patient must have had pulmonary function tests performed at Yale-New Haven Hospital at any time from 1978 to the present.

The first two criteria were arbitrarily decided upon to eliminate those patients with metastatic focal disease. The bone scans of all patients who met criteria 1, 3, and 4 were reviewed.

INTERPRETATION OF BONE SCANS

All bone scans were initially reviewed by the author; those with lesions which had appeared over the greater than

six month interval suggestive of focal metastatic disease were eliminated from further study. For each patient then to be included in the study the author chose the best technical scan. The chosen bone scans were then reviewed without knowledge of the patient's pulmonary function test results and without the chest radiographs having been seen by an experienced nuclear medicine observer who in collaboration with the author placed the images into three groups: visible manubrio-sternal joint, vague suggestion of an MSJ, or a non-visible MSJ. This was determined independently on three views; the right anterior oblique, the left anterior oblique, and the anterior. A patient was included in the visible joint category if the joint was visible on any of three views.

A "bone scan score" was created. A patient received two points for a visible angle; one point for a vague angle and no points for a non-visible angle. Thus, the maximum score was six if the angle was clearly visible on all three views while the minimum score was zero if the angle was not visualized on any view.

In addition to the determination regarding the joint, the author made a drawing of the body of each of the sterna and particularly noted areas that appeared cystic, presented as hot spots, or that suggested anatomic anomoly. The region(s) of the sternum with the most intense uptake was/were also noted.

CHEST RADIOGRAPH

The diagnosis of emphysema or obstructive pulmonary disease by chest radiograph is notoriously difficult (Knott, Laws, Simon, 1963, Sutinen, Reid, Nicklaus, Thurlbeck, Simon, 1973, and Burki). The author did, however, choose to evaluate several of the characteristic findings of emphysema on chest radiographs and to correlate these with the bone scan results. All aspects of the chest radiograph were interpreted by the author. Since the evaluation of the MSJ was particularly difficult a consensus opinion of the author and her thesis advisor was used for this area.

The following questionnaire (Figure 11) was completed for each set of PA and lateral chest radiographs; the criteria used are described below.

Diaphragms

The diaphrams were judged to be high, normal, low or flat. When possible the right diaphragm was evaluated. If there was a right pleural effusion or right pleural disease the left side was evaluated. The diaphragm was called "low" if the level of the right dome was at or below the anterior end of the seventh rib (Simon, 1973). The diaphragm was called flat if a line drawn vertically from the top of the right dome to a second line drawn from the cardiophrenic to

the costophrenic recess was less than 1.5cm. (Simon, 1978, p. 10).

The Retrosternal Translucent Zone

The retrosternal translucent zone represents the aerated portion of the two lungs in front of the aorta. Its depth normally measures less than 3.5cm. (Simon, 1963). The depth of the retrosternal space was measured by choosing a point on the sternum 3cm. below the manubriosternal joint and measuring "horizontally backwards" from this point to the anterior margin of the ascending aorta. Although it is often difficult to select a point on the aorta this can usually be done with enough "fairness" to make the measurement reliable and reproducable (Simon, 1978, p. 28). To account for possible errors the depth of the retrosternal translucent zone was measured in intervals, i.e. less than 2cm., 2-3cm., 3-4cm., 4-5cm. or greater than 5cm.

The retrosternal translucent zone also tends to extend down further in patients with emphysema; in normal persons the zone usually ends greater than six cm. from the diaphragm (Simon, 1978, p. 28). This was also measured in ranges: within 1-2cm. of diaphragm, within 2-4cm., within 4-6cm. and greater than 6cm.

Bulla

The presence or absence of bulla as well as the number of bulla were noted.

Peripheral Vascular Markings

Peripheral vascular markings were judged to be normal, increased (on a scale of 1-3) or decreased (on a scale of 1-3).

PULMONARY FUNCTION TESTS

Pulmonary function test results were obtained from the Pulmonary Function Laboratory of the Section of Pulmonary Medicine, Department of Internal Medicine, Yale-New Haven Hospital.

The observed and predicted FEV_1, the FEV_1/FVC ratio, the observed and predicted TLC and the RV/TLC ratio were recorded for each patient.

The FVC is the volume forcefully exhaled after maximum inspiration while the FEV_1 is the volume of air forcefully exhaled in one second after a maximum inspiration. In obstructive pulmonary disease the FVC is decreased because of premature airway closure which limits the amount of expired air. The FEV_1 and FEV_1/FVC ratio are also reduced because the rate of expiration is decreased by increased airway resistance. In restrictive disease, the FVC is low because the lung or chest wall cannot expand but the FEV_1 is not reduced proportionately because airway resistance is normal. This results in a normal or high FEV_1/FVC ratio (West). It

follows, therefore, that the FEV_1/FVC ratio is a more specific index of obstructive pulmonary disease than is the FEV_1 alone.

Other lung volume measurements are often helpful. TLC is the volume in the lungs at full inspiration while RV is that volume remaining after a maximal expiration. The TLC and RV/TLC ratio are increased in situations in which the airway resistance is increased, i.e. in emphysema and bronchitis.

RADIOGRAPHY OF THE MANUBRIO-STERNAL JOINT

Imaging of the sternum with standard radiographic technique is usually unsatisfactory because the overlying ribs, spinal column, and soft tissues obscure bone detail in frontal projections (Destouet). The lateral chest radiograph may sometimes show fractures or metastases. An oblique view projects the sternum off of the spine but this view is often inadequate if the patient is large, has a depressed sternum, or has severe sternal disease (McKinlay). Linear tomography may be helpful (Morag) but the procedure is time consuming and there are often "ghost shadows of the spine" which confuse the image of the sternum. McKinlay and Wright (1967) demonstrated that inclined frontal (rotational) tomography as opposed to linear tomography can easily visualize the sternum and lesions within it as well as the MSJ and

sterno-clavicular joint. The thin cortices and low mineral mass of the sternum also make its visualization difficult (Meschan, Lee).

In the present study, the MSJ was studied on lateral chest radiograph; it was placed in one of five categories as described by Grosbois (1981):

1. Normal.

2. Hazy, slightly narrowed, slightly osteoporotic or having some subchondral bone condensation.

3. Having irregular margins, increased osteoporosis and/or condensation, or having a narrowed joint space.

4. Having increases in the previous signs, erosion, or vacuole formation.

5. Having a partially or totally fused joint space.

Where possible, the angle of the MSJ was measured.

STATISTICS

Because of the small sample size when it was possible to create a 2x2 contingency table the exact probability "p" was calculated by the formula:

$$P = \frac{(a+b)!(c+d)!(a+c)!(b+d)!}{a!b!c!d!(a+b+c+d)!}$$

where a, b, c and d represent areas on a 2x2 table.

	Outcome		
Class	Yes	No	Totals
I	a	b	a+b
II	c	d	c+d
	a+c	b+d	a+b+c+d

This was done because the Chi-square test of significance is considered unreliable when dealing with situations where a, b, c or d is less than four (Batson, p. 48).

Means, standard errors and standard deviations were calculated for several parameters. Means were compared with the students t test which is valid whenever the distribution of the individual values approaches a normal distribution. "t" is essentially the ratio of the difference between two means to the standard error of the difference and is calculated using the formula

$$t = \frac{\bar{Y}_1 - \bar{Y}_2}{\sqrt{\frac{S_1^2}{N_1} + \frac{S_2^2}{N_2}}} \qquad \text{where}$$

$\bar{Y}_1$ and $\bar{Y}_2$ and S_1^2, and S_2^2 are the respective means and variances of the two groups. N_1 and N_2 are the respective numbers of individuals in the two groups (Batson, pp. 16-18).

RESULTS

RESULTS

929 bone scans of adults were performed at Yale-New Haven Hospital from August 12, 1981 to June 29, 1982. Thirty-one of these adults had two bone scans, pulmonary function tests and a chest radiograph. Six of these thirty-one patients were eliminated from the study:

one patient's films could not be located;

one patient had had a CABG and sternotomy in the interval between bone scans, and

four patients had focal lesions that had changed between bone scans.

Of the remaining twenty-five patients there were seven males and eighteen females. Twelve had breast cancer, three had prostate cancer and one each had lung cancer, SLE, Seminoma, bladder cancer, and head and neck cancer. Six patients had cancer whose primary location was unknown to us. The demographic characteristics of the patient population are detailed in Table 6.

CHEST RADIOGRAPHS

The features of the chest radiographs included in the study are detailed in Table 7 and discussed below.

Diaphragms

Ninty-two percent of the diaphragms were of normal height. This was determined by examination of the right

diaphragm in all but six cases. One patient had a high diaphragm while one had a low diaphragm. The height of the diaphragm, then, bore no relationship to visibility of the MSJ or pulmonary function.

The Retrosternal Translucent Zone

The depth of the retrosternal translucent zone was normal according to Simon's (1978) criteria in all but one patient who had a visible angle. There was, however, a slightly significant difference in the depth between synostosed and non-synostosed patients (p=0.06). (See Table 8.) The average value for the depth of the retrosternal space was calculated using the midpoint value for each category, i.e. if a depth was measured as between 2 and 3cm. it was indexed as 2.5cm.; the less than 2cm. category was indexed as 1.5cm.

The extension of the retrosternal translucent zone was not significantly different in the synostosed and non-synostosed classes.

There was not a statistically significant difference in the retrosternal translucent zone depth and extension between the visible and vague or non-visible MSJs on bone scan patients. (See Table 9.)

Bulla

No patient had bullous disease.

Peripheral Vascular Markings

All peripheral vascular markings were within normal limits.

CONDITION OF THE MSJ

In three of twenty-five patients, MSJs could not be visualized on the plain film. The remaining twenty-two angles were either normal, minimally diseased or synostosed with eight (36%) being synostosed. (See Figure 12.) One patient had an osteophyte present. (See Figure 13.)

Patients with synostosed MSJs tended to have slightly shallower MSJs ($169^{\circ} + 3.9$ vs. $161^{\circ} + 2.3$) when compared with patients with non-fused MSJs; the difference, however, did not achieve statistical significance ($p=.08$).

There was no significant difference between patients with fused and non-fused MSJs with respect to age, sex, or pulmonary function testing. (See Table 8.)

As expected, presence or absence of synostosis of the MSJ turned out to be an important determinant of bone scan visibility of the MSJ. (See Table 10.) The mean bone scan score of the synostosed MSJs was significantly less than that of the non-fused MSJs ($1.88 \pm .58$ vs. $4.06 \pm .8$, $p=.04$). Further, of the eight bone scans in which the MSJ was most clearly visible, i.e. those with bone scan scores of 6, none were noted to be synostosed on chest radiograph ($p=.02$).

The MSJ angle also is an important determinant of bone scan visibility of the MSJ. MSJs with bone scan scores of 6 had more acute angles than those with bone scan scores of five or less ($156^{o} + 2.8$ vs. $166.8^{o} + 2.3$, $p < .01$). (See Table 11.)

Neither the depth nor degree of extension of the retrosternal translucent zone had any direct relationship with MSJ bone scan visibility.

THE MSJ AND PULMONARY FUNCTION

The raw data is presented in Tables 12 and 13 and analyzed below. Figures 14 through 16 illustrate examples of visible, vague and non-visible joints.

The assumption of the working hypothesis is that patients with obstructive pulmonary disease will use their accessory respiratory muscles more than normal patients and will therefore have increased MSJ MDP uptake by virtue of increased angle movement. If the MSJ is fused, the assumption cannot hold and the hypothesis cannot be expected to apply. Therefore, in evaluating the relationship between MSJ bone scan visibility and the presence of obstructive pulmonary disease, those patients with synostosis are excluded from statistical analysis. As stated above there is no statistically significant difference between the pulmonary func-

tion of those with synostosed or non-synostosed joints, therefore excluding those with synostosed joints does not introduce any bias or error into the results.

Patients with visible MSJs and without synostosis had lower FEV_1 and FEV_1/FVC ratios than patients with vague or nonvisible MSJs and no synostosis. The difference between the FEV_1/FVC ratio in the two groups (67.9% $\pm$5.7% vs. 80.9% $\pm$2.5%) reaches statistical significance at the $p < 0.05$ level by the students t test. In fact by all other parameters, the group with visible MSJs had PFT values more indicative of obstructive pulmonary disease than the non-visible or vague MSJ group, i.e., lower FEV_1, greater TLC and greater RV/TLC ratio.

VARIABILITY IN THE APPEARANCE OF THE STERNUM'S SCINTOGRAPHIC IMAGE

Considerable variability was noted in the appearance of the sternum on MDP bone scan. Six patients had cystic appearing mesosterna on at least one view (Figure 17) while four showed focal spots at the mesosternal border. Another patient's bone scan demonstrated a vague suggestion of a joint between the first and second and third and fourth sternebrae (Figure 17). The area of one patient's MSJ was easily misinterpretable as metastatic (Figure 18) but because of the comparison scans available the author and her

thesis advisor were able to state with confidence that this radionuclide uptake represents a "vague" MSJ.

DISCUSSION

DISCUSSION

The present study was designed to test the hypothesis that pulmonary function and scintigraphy of the MSJ are related. This hypothesis is based upon the assumptions that individuals with COPD who make greater use of the accessory muscles of respiration will have greater movement of the MSJ during normal respiration and that this will cause a detectable increase in radionuclide uptake. In order to demonstrate an association between MSJ visibility and pulmonary function a retrospective study was undertaken. Over 900 cases were reviewed to find 17 persons who had the necessary bone scans, non-synostosed MSJs and pulmonary function tests.

In addition to documenting that MSJ uptake correlates with pulmonary function this is one of the first studies to document that MSJ uptake is a normal variant. It was demonstrated that the presence of this normal variant is related to the presence or absence of synostosis and the angulation of the joint. One would expect a fused joint - whether it be secondary to cortical or matrical synostosis - not to be visible on MDP bone scans. In a matrically synostosed MSJ the intra-skeletal composition of the manubrium and mesosternum would be continuous and therefore one could not view any focal activity at the MSJ. In a cortically

synostosed joint a band of compact bone unites the manubrium and body while separating the cancellous bone of one from the other. The presence of the compact bone band will cause the joint to be non-visible but may create a vague suggestion of a joint because of the difference in blood supply between compact and cancellous bone.

The MSJs with the greatest visibility had statistically significant ($p < .01$) greater angulation of the MSJ than less or non-visible MSJs. In an attempt to explain this unexpected result it was reasoned that since the non-synostosed MSJs tended to have more acute angles ($p = .08$) the greater visibility of acute angles was secondary to their lack of synostosis. However, even when only the non-synostosed angles were included in statistical analysis there was still a relationship between visibility and angulation ($p < .05$). Other hypotheses are (1) that a more angulated joint is subjected to more stress or (2) that more angulated joints have a greater range of motion so that when they are flexed during respiration they bend more and therefore develop a greater blood supply than less angulated joints; this increase in blood supply might produce a more visible joint.

Recognition of MSJ visibility as a normal variant should alleviate some of the difficulty in interpretation of the sternal image on MDP bone scan.

Ono, et al. (1980), described a "focal concentration of radionuclide at the sternal angle," which they termed the "sternal hot spot." By means of a "long period of observation" they deduced that this finding was a normal variant of uptake at the MSJ and not a metastatic focus; it was present in 23% of 290 patients.

Because their images appear to be of poor quality and the text is in Japanese one can only speculate upon how the presence of the "hot spot" correlates with what is in this work termed a visible angle. This author believes that we are talking about two separate albeit possibly related findings. Ono, et al., probably called a scan positive if the area of the MSJ was the darkest area of the sternum or if the area was significantly darker than the adjacent areas of the manubrium or mesosternum. This criteria would include most of the patients in the present study who were placed in the visible or vague category and would exclude most of those patients whose sternal angle we could not visualize. Their terminology would not differentiate between a visible and a vague angle.

Despite the relative good pulmonary function of the majority of the sample population and the small size of the sample population the results of the study support the hypothesis that pulmonary function correlates with MSJ visibility on MDP bone scans and the assumptions on which it is

based, i.e., the statistically significant correlation of FEV_1/FVC with visible angles indicates that those persons with visible angles are more likely to have COPD.

Because of the statistically significant results it is suggested that the stated hypothesis merits further investigation. Study of the hypothesis would be facilitated by a prospective study of a population of persons with non-synostosed angles. A suitable sample would exclude persons with cancer, arthritis and prior sternotomy and would include persons with significantly compromised pulmonary function as well as normal controls.

Ono, et al. (1980) suggested that there was a correlation between the presence of the hot spot and the shape of the sternum; any further studies should include this variable.

Two patients in the present study had fused MSJs on chest radiograph but clearly visible MSJs on bone scan. This can be explained by an error in interpretation of either the bone scan or the chest radiograph but is more likely explained by osteoarthritic changes, i.e. lipping of the MSJ can cause it to appear fused on chest radiograph when it is actually not fused.

Thirty-six percent of the patients in this study had fused MSJs; this is in contrast to the ten percent that was

found by Ashley (1954). This is probably not accounted for by the high percentage of females in this study since Trotter's study of 877 patients failed to reveal a statistically significant difference between males and females, but is probably accounted for by the small sample size.

This study confirms Ono's (1980) description of variability of the sternal image. (Figure 19). The most common mesosternal variants noted were a cystic appearance of the mesosternum and focal hot spots along the mesosternal borders. The mesosternum was felt to have a cystic appearance in 24% of patients in the present study. This was present in eight out of thirty-two (25%) of Ono's patients. Based on a careful study of sternal anatomy and embryology the most likely causes are persistance of cartilaginous ossification centers and/or the presence of a sternal foramen.

The present study also confirmed Ono's findings of focal concentrations at the mesosternal borders. This was noted in four of the study's twenty-five patients while Ono noted this in four out of thirty-two of his patients. Possible causes of this finding include ossification of costal cartilages and persistance of joints between sternebrae.

In conclusion this study has demonstrated that uptake at the MSJ is a normal variant, that the presence of this uptake correlates with pulmonary function and that the variability of the sternum's scintigraphic image can be explained by careful study of the anatomy and embryology of the sternum.

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TABLES

AGE	WHITE MALE No.	WHITE MALE Synostoses	WHITE MALE Percent	NEGRO MALE No.	NEGRO MALE Synostoses	NEGRO MALE Percent	WHITE FEMALE No.	WHITE FEMALE Synostoses	WHITE FEMALE Percent	NEGRO FEMALE No.	NEGRO FEMALE Synostoses	NEGRO FEMALE Percent
10-19	1	0		6	0		2	0		5	0	
20-29	10	1	11.0	45	3	6.6	0			18	1	5.8
30-39	21	2	9.5	51	3	5.8	5	1	25.0	22	2	10.0
40-49	73	13	17.8	70	8	11.4	4	0		10	1	11.1
50-59	87	5	5.7	47	2	4.2	8	3	60.0	10	2	25.0
60-69	129	16	12.4	42	4	9.5	11	3	37.5	10	2	25.0
70-79	84	12	14.2	27	6	28.5	13	5	62.5	6	0	
80-89	18	0		8	4	50.0	1	0		5	0	
90-99	1	0		0			1	1	100.0	2	0	
Unknown	11	1	9.1	11	0		0			2	1	50.0
Total	435	50	11.5	307	30	9.8	45	13	26.7	90	9	10.0

(Trotter)

Incidence of Synostoses According
to Race, Sex and Age

TABLE 1

Observer		Age Groups									Total	
		1-9	10-19	20-29	30-39	40-49	50-59	60-69	70-79	80-89	No.	%
Van Gelderen (1924)		-	1/31	0/10	2/11	2/16	2/20	3/20	2/17	1/17	13/132	9.9
Passler (1931)		0/26	0/38	2/129	7/97	7/124	17/228	16/212	9/118	0/28	58/1000	5.8
Trotter (1934)		-	0/14	5/73	8/99	22/157	12/152	25/192	23/130	4/32	99/849	11.7
Author: African Series		-	0/7	4/34	4/26	2/14	2/8	2/6	1/3	-	15/98	15.3
Manchester		0/20	0/7	1/6	1/12	4/10	3/18	3/23	3/26	1/8	16/130	12.3
Liverpool		0/24	2/72	6/82	13/132	14/124	18/86	4/44	1/12	0/2	58/578	10.0
Totals	No.	0/7	3/169	18/334	35/334	51/445	54/512	53/497	39/306	6/7	259/2787	
	%	0.0	1.8	5.4	9.3	11.5	10.6	10.6	12.7	7.9		9.3

(Ashley, 1954)

Numbers and Percentages of Individuals with Synostosis at the Manubrio-Sternal Joint in 10 Year Age Groups.

TABLE 2

MSJ	Non-rhematoid Subjects	Ankylosing Spondylitis
Normal	538	35
Fused	32 (5.5%)	13 (23%)
Pathologic Changes	0	9 (15.8%)

(After Solovay and Gardner)

Condition of the MSJ in Ankylosing Spondylitis

Table 3

	Erosions	Reactive Sclerosis	Ankylosis	No Change
RA	51 (59%)	4	7	25
Controls	12 (12%)	7	7	69

Radiologic Changes in the Manubrio-Sternal Articulation

(After Laitinen)

TABLE 4

Microradiographic Findings in MSJs of
Non-Rheumatoid and Rheumatoid Subjects

	Non-Rheum Pts. (20)	RA Pts. (11)
Joint cavity	9	1
Osteophytes	10	8
Sclerosis	6	7
Indentation	14	7
Erosions	3	6
Osteoporosis	11	5
Arckylosis	0	1

(after Kormano)

TABLE 5

Patient	Age	Sex	Disease
1	49	F	Breast Cancer
2	67	M	Prostate Cancer
3	47	F	Breast Cancer
4	72	M	Bladder Cancer; Osteoarthritis
5	24	F	Systemic Lupus Erythematosus
6	56	M	Cancer
7	60	F	Cancer
8	65	M	Prostate Cancer
9	52	F	Breast Cancer
10	53	M	Prostate Cancer
11	63	F	Breast Cancer
12	60	F	Cancer
13	30	F	Cancer
14	70	M	Lung Cancer
15	65	F	Breast Cancer
16	59	F	Breast Cancer
17	59	F	Breast Cancer
18	69	F	Breast Cancer
19	38	M	Seminoma
20	58	F	Breast Cancer
21	64	F	Thyroid and Squamous Cell of Neck
22	53	F	Breast Cancer
23	65	F	Breast Cancer
24	74	F	Cancer
25	53	F	Cancer

Demographic Characteristics of the
Patient Population

TABLE 6

Chest Radiograph Findings

Patient	Diaphragms: High	Diaphragms: Normal	Diaphragms: Low	Retrosternal Translucent Zone Depth: <2cm	Depth: 2-3cm	Depth: 3-4cm	Depth: 4-5cm	Extension: 4-6cm	Extension: > 6cm	MSJ: Obscured by Soft Tissue	MSJ: Normal	MSJ: Class 2 ¢	MSJ: Class 3 ¢	MSJ: Class 4 ¢	MSJ: Partial or total fusion	Measure of Angle	Other
1		x		x					x		x					160	
2		x					x		x		x					145	
3		x			x				x			x				152	
4		x				x		x			x					160	
5		x		+				+		x						---	
6		x				x		+				x				165	
7		x			x			+				x				164	Severe Right Pleural Disease
8		x				x			x						x	180	Honeycombed Reticulonodular Pattern
9		x		x					x			x				160	Pleural Lesion Right Lung
10		x				x			x		x					159	Interstitial Lung Disease
11		x			x			x		x						---	
12		x			x			x							x	#	
13		x				x		+							x	172	
14		x			x				x		x					164	Right Upper Lobe Mass
15		x		x					x		x					165	
16		x			x			x							x	160	Right Pleural Disease
17		x			x				x			x				180	
18			x			x			x						x	172	
19		x			x			+							x	180	Right Pleural Dusease
20	x				x				x	x						---	
21		x		x					x			x				168	Nodular Metastases; Osteophyte
22		x			x				x						x	156	
23		x			x				x			x				150	Left Pleural Effusion
24		x				x			x						x	163	
25		x			x				x		x					163	

Table 7

Legend to Table 7

✓Left side evaluated

+ Measurement not possible

¢ See page 38 for description of classes

MSJ should be well seen but no joint is identifiable

	Synostosed	Non-Synostosed	p
Age	56.0 ± 5.7	57.5 ± 2.8	$p > .1$
Sex M F	2 6	5 9	$p > .1$
FEV_1	84.4 ± 6.3	83.4 ± 7.1	$p > .1$
FEV_1/FVC	74.1 ± 3.1	73.2 ± 3.7	$p > .1$
TLC	84.4 ± 4.2	91.8 ± 5.2	$p > .1$
RV/TLC	32.8 ± 3.1	38.9 ± 2.9	$p > .1$
MSJ ∠	169° ± 3.9	161° ± 2.3	$p = 0.08$
RTZD* (cm)	3.13 ± 0.20	2.53 ± 0.22	$p = 0.06$
Visuable	2	8	$p = 0.13$
Non visable or vague	6	6	
Bone Scan Score	1.88 ± .58	4.06 ± .80	$p = .04$
Bone Scan Score 6	0	8	$P = .02$
Bone Scan Score < 6	8	9	

* retrosternal translucent zone depth

Patient characteristics and Synostosis of the MSJ

Table 8

		Visable	Vague or Non-Visable	p
Age		56.0 ± 4	58.3 ± 4	$p > .1$
Sex	M	5	2	$p > .1$
	F	7	11	
FEV_1 *		76.6 ± 10.7	93.1 ± 7.7	$p > .1$
FEV_1/FVC*		67.9 ± 5.6	80.9 ± 2.5	$p < .05$
TLC *		93.4 ± 8.4	89.4 ± 5.4	$p > .1$
RV/TLC*		39.3 ± 4.6	38.3 ± 3.6	$p > .1$
Synostosis		2	6	$p = .13$
Non fused		8	6	
MSJ $\measuredangle$		161 ± 3.4	166 ± 2.7	$p > .1$
RTZD†		2.86 ± .29	2.65 ± .20	$p > .1$

* Subjects whose chest radiographs revealed evidence of MSJ synostosis were excluded from this statistical analysis for reasons given in text.

† Retrosternal translucent zone depth.

Patient characteristics and MSJ visibility on MDP bone scans

Table 9

	Visible MSJ	Not Visible MSJ	Vague MSJ
Normal	4 (40%)	2 (29%)	1 (20%)
Slightly Diseased	4 (40%)	1 (14%)	2 (40%)
Synostosed	2 (20%)	4 (57%)	2 (40%)
Not Visible	2		1

Condition of the MSJ and Synostosis

Table 10

MSJ ANGLE AND BONE SCAN SCORE

	MSJ Angle (Degrees)
Bone Scan Score = 6	156.0 ± 2.8
Bone Scan Score ≤ 5	166.8 ± 2.3

$p < .01$

Table 11

Patient	Projection: RAO Visible	RAO Non-Visible	RAO Vague	LAO Visible	LAO Non-Visible	LAO Vague	Anterior Visible	Anterior Non-Visible	Anterior Vague	Darkest Point: MSJ	Darkest Point: Mesosternal or manubrial border	Other
1	x			x			x			x		
2	x			x			x				x	
3	x			x			x			x	x	Cystic Area
4	x			x			x			x		Focal Spots
5	x			x			x			x		
6		x		x			x			x	x	
7	x					x	x			x	x	Focal Spots
8	x					x	x			x	x	
9	x			x			x			x	x	Cystic "hole" on RAO
10	x			x			x				x	Focal Spots
11	x			x			x			x		
12			x	x					x		x	Vaguely cystic
13		x			x			x		x	x	
14	?				x			x			x	Cystic Area
15		x			x			x			x	
16		x			x			x			x	
17		x			x			x		x	x	
18		x			x			x			x	
19		x			x			x			x	Focal Spot
20			x			x			x		x	
21			x			x			x	x	x	Area interpretable as metastatic
22			x			x			x	x	x	
23			x			x			x	x	x	**
24			x			x			x	x	x	Cystic Area
25			x			x			x	x	x	

? Technically poor view; ** Vague suggestion of joint between first and second and third and fourth sternebrae as well as cystic appearance of mesosternum

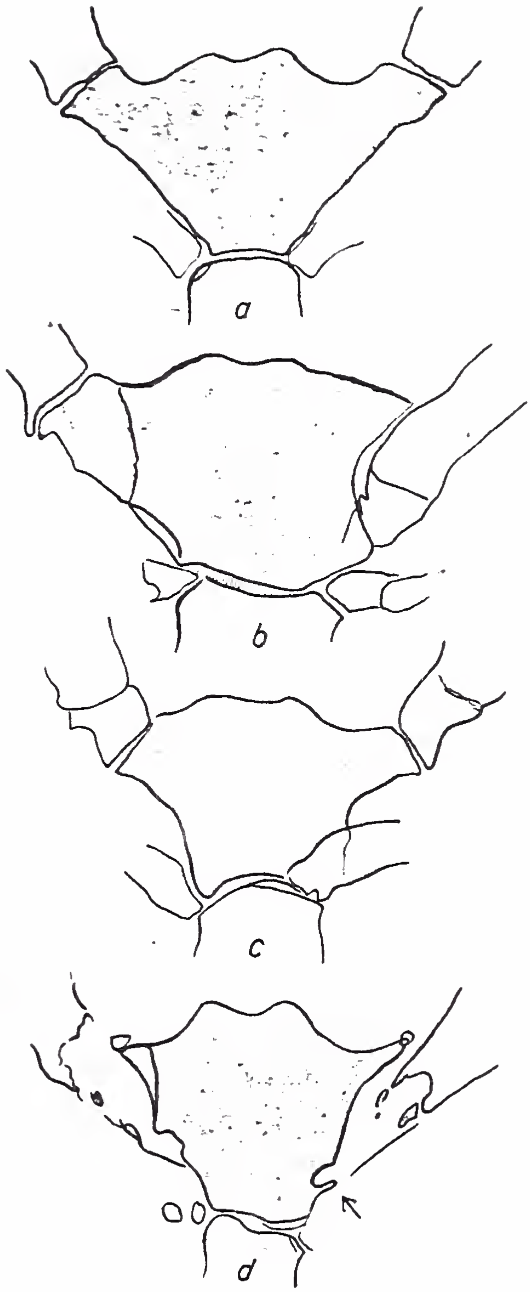
Bone Scan Results
Table 12

Pulmonary Function Test Results

Patient	FEV_1 (% Predicted)	FEV_1/FVC (%)	TLC (% Predicted)	RV/TLC (%)
1	114	84	113	36
2	19	32	123	75
3	109	72	104	26
4	109	73	110	43
5	51	86	55	34
6	41	51	79	45
7	64	67	68	34
8	102	81	83	21
9	76	84	65	33
10	90	72	93	30
11	93	58	124	37
12	82	69	94	38
13	56	76	65	43
14	98	74	104	42
15	125	86	94	25
16	78	83	75	36
17	96	82	101	49
18	91	70	90	36
19	78	71	79	22
20	105	90	89	33
21	79	78	72	33
22	110	83	98	28
23	81	83	71	37
24	78	60	91	38
25	68	73	95	49

Table 13

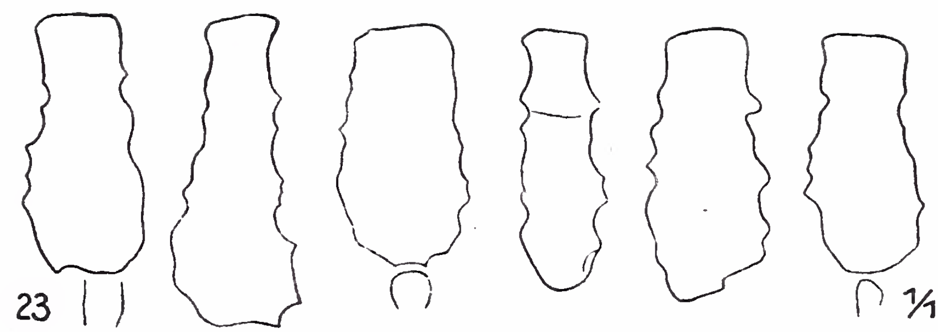
FIGURES



(Zimmer)

Variation in the Shape of the Manubrium

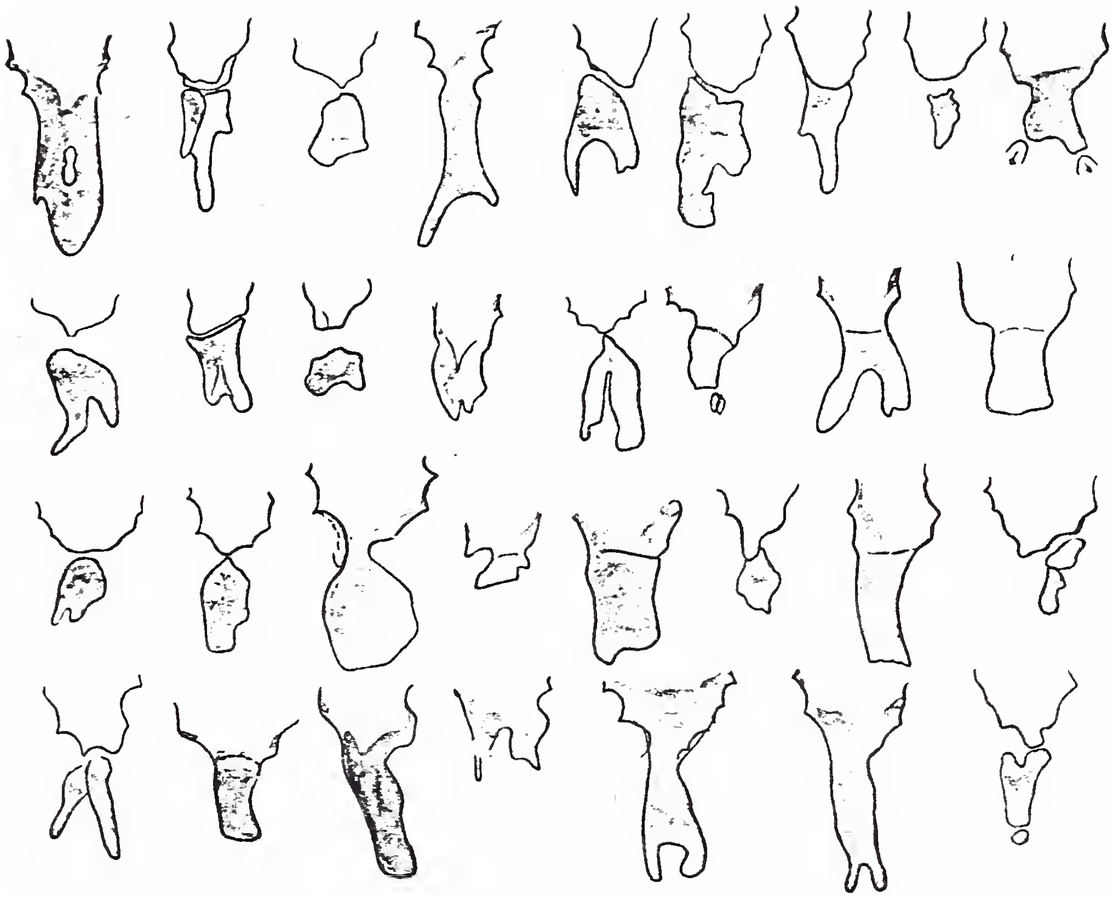
Figure 1



(Zimmer)

Variation in the Shape of the Mesosternum:
Six Siblings

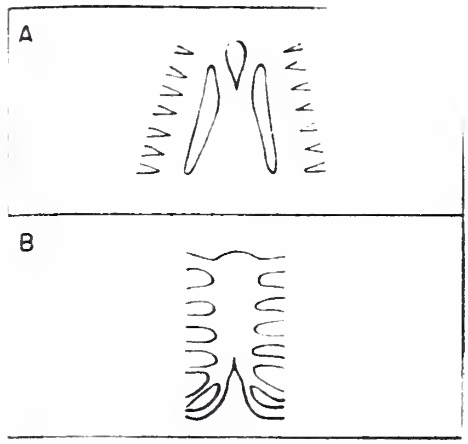
Figure 2



(Zimmer)

Variation in the Form of the Xiphoid Process

Figure 3

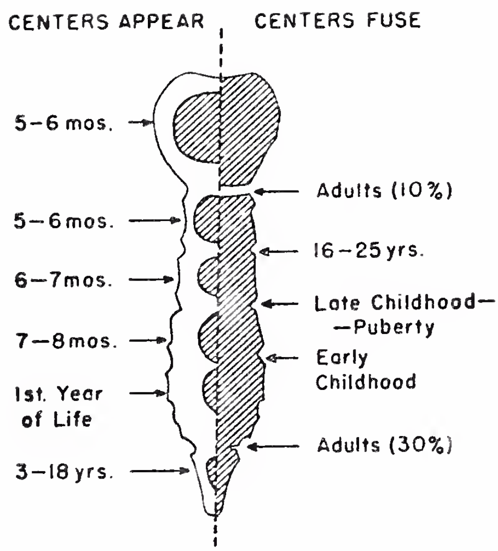


(Currarino)

A - The Mesoblastic Primordia: Two Lateral Bands and a Median Rudiment

B - Plate of Hyaline Cartilage Originating from the Chondrification and Mid-line Fusion of the Primordia

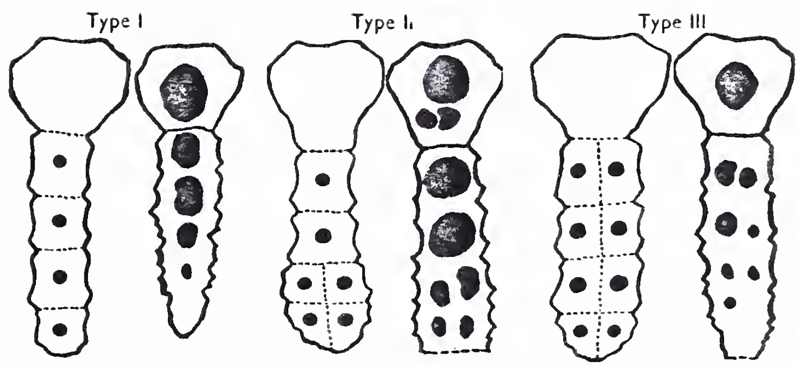
Figure 4



(Currarino)

Ossification and Fusion of the Sternebrae

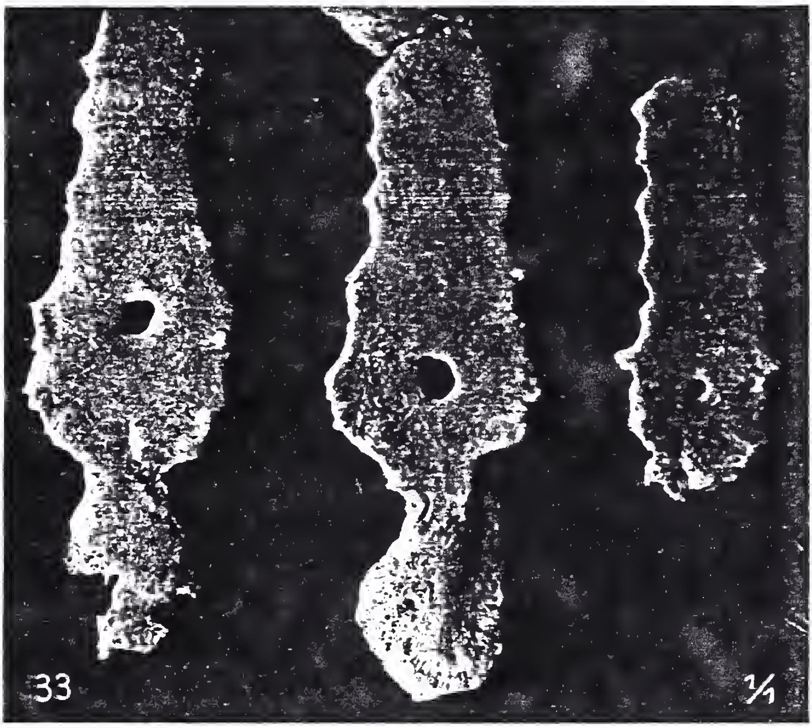
Figure 5



(Ashley, 1956)

Basic Ossification Patterns

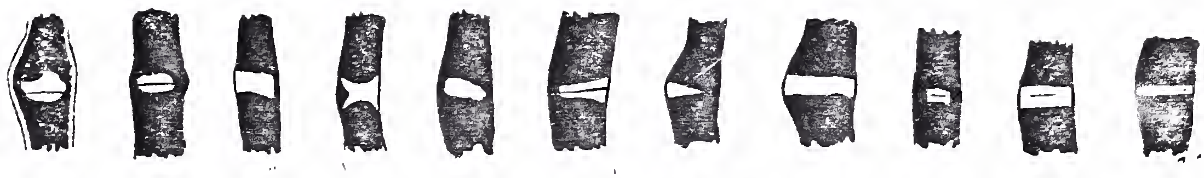
Figure 6



(Zimmer)

Sternal Foramen

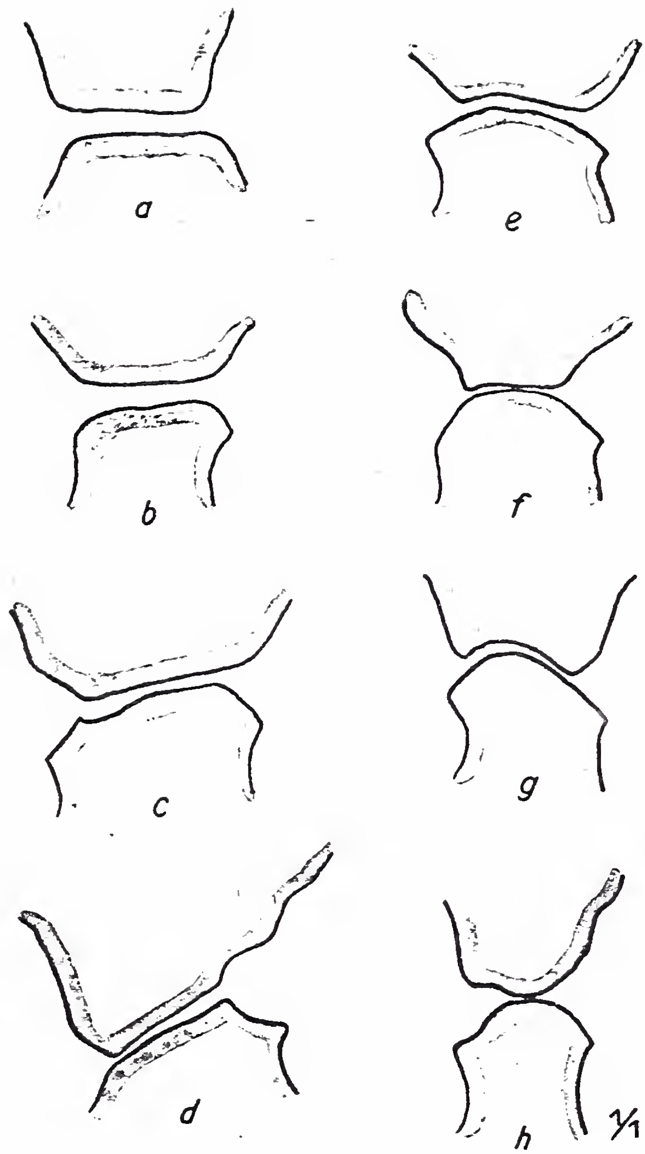
Figure 7



(Zimmer)

Variation of Disc Form

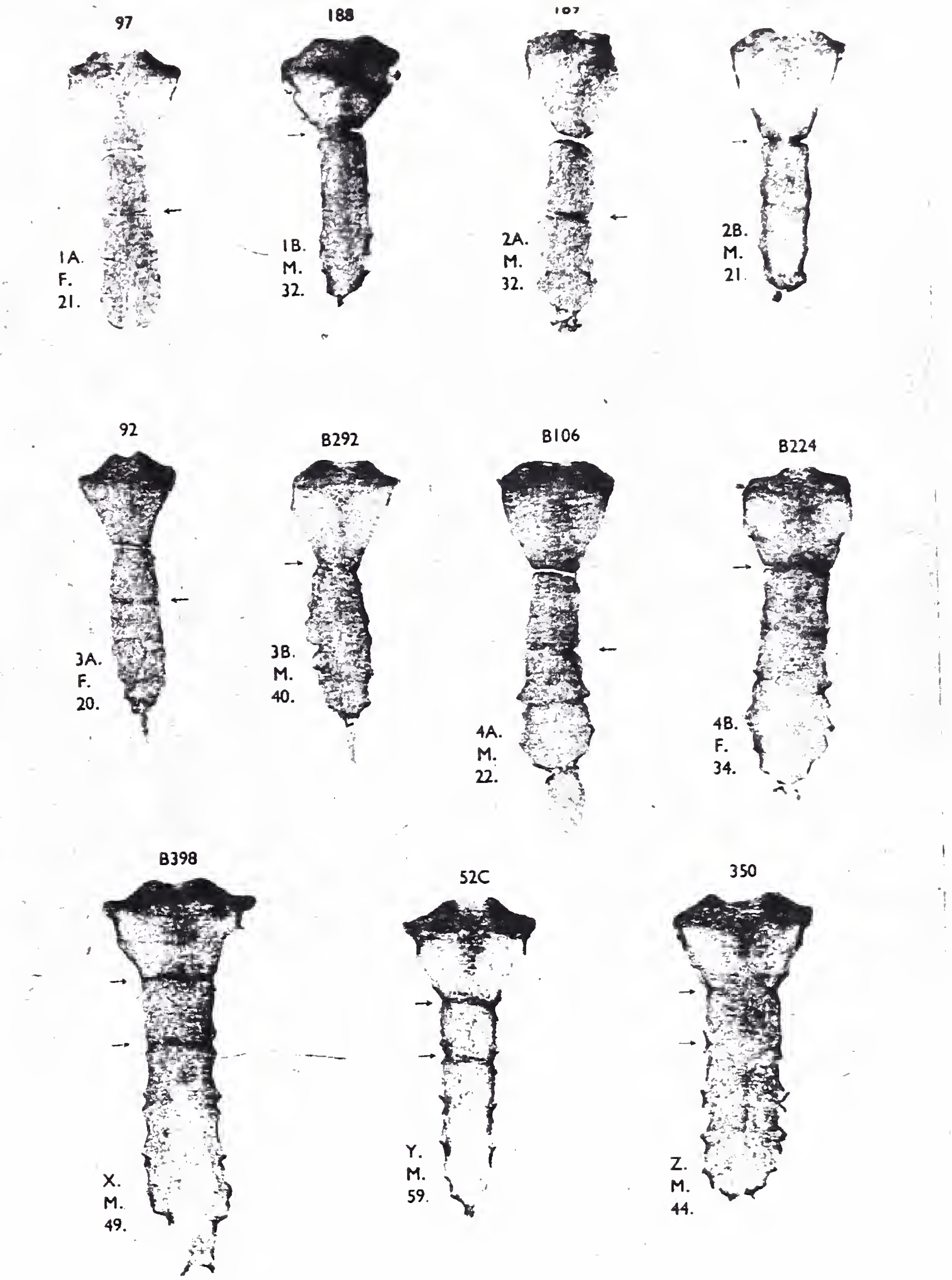
Figure 8



(Zimmer)

Variation of the Form of the Articular Surfaces

Figure 9



Matrical Synostosis

Radiologic evidence of the similarity of union between the first and second sternebrae and the abnormal union between manubrium and mesosternum. In each pair of sterna the appearance of the pre-mesosternal joint in B is comparable to the appearance of the joint between the sternebrae in A. In X, Y, and Z the MSJ and the joint between the sternebrae cannot be distinguished by the extent or nature of the union.

(Ashley, 1956)

Figure 10

Name________________________________

Date________________

Diaphragms: High
Normal
Low
Flat

Retrosternal Translucent Zone:

Depth: less than 2cm   2-3cm   3-4cm

4-5cm   greater than 5cm

Extension: within 1-2cm of diaphragm
within 2-4cm of diaphragm
within 4-6cm of diaphragm
greater than 6cm from diaphragm

Bulla: 0 1 2 3 4 greater than 4

Peripheral Vascular Markings:

Normal   Diminished (1+ 2+ 3+)   Accentuated (1+ 2+ 3+)

Visibility of Manubrio-sternal Angle:

____Obscured by Soft Tissue

1-Normal

2-Hazy, slight narrowing, slight osteoporosis or subchondral bone condensation.

3-Irregularity of the margins, increased osteoporosis and or condensation, narrowing of the joint space

4-Increase in the previous signs, erosion, vacuole formation

5-Partial or total fusion

Measure of MSJ:________________

Other:____

Chest Radiograph Questionnaire

Figure 11

(A) (B)

The Manubrio-Sternal Joint on Lateral Chest Radiograph

(A) Normal MSJ-patient No. 2
(B) Synostosed MSJ-patient No. 19

Figure 12

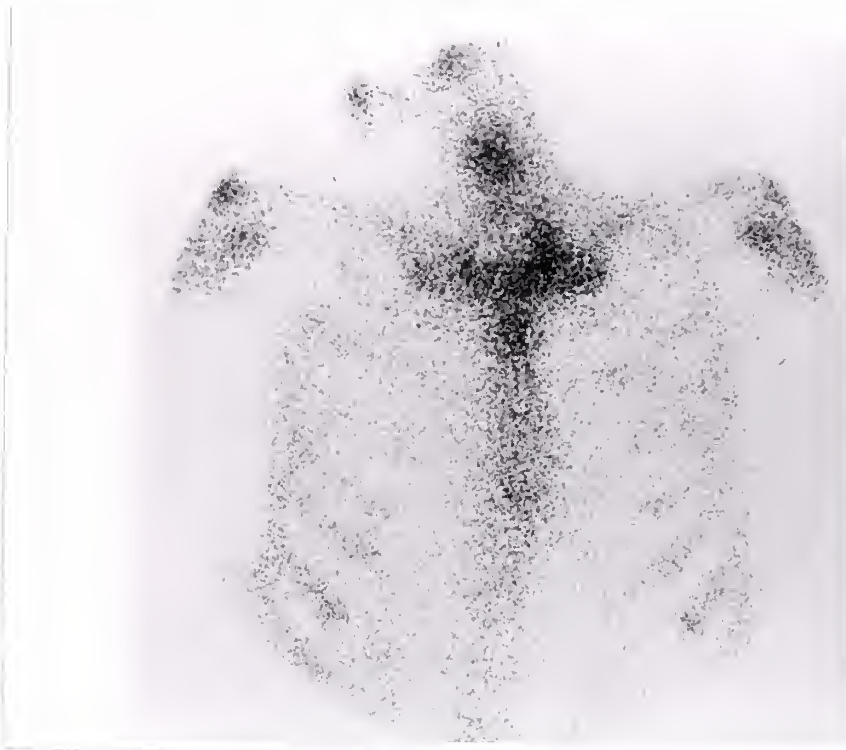
Manubrio-Sternal Joint with Osteophyte

Figure 13

Visible MSJ

Patient No. 2

Figure 14



Vague MSJ

Patient No. 20

Figure 15

Non-Visible MSJ

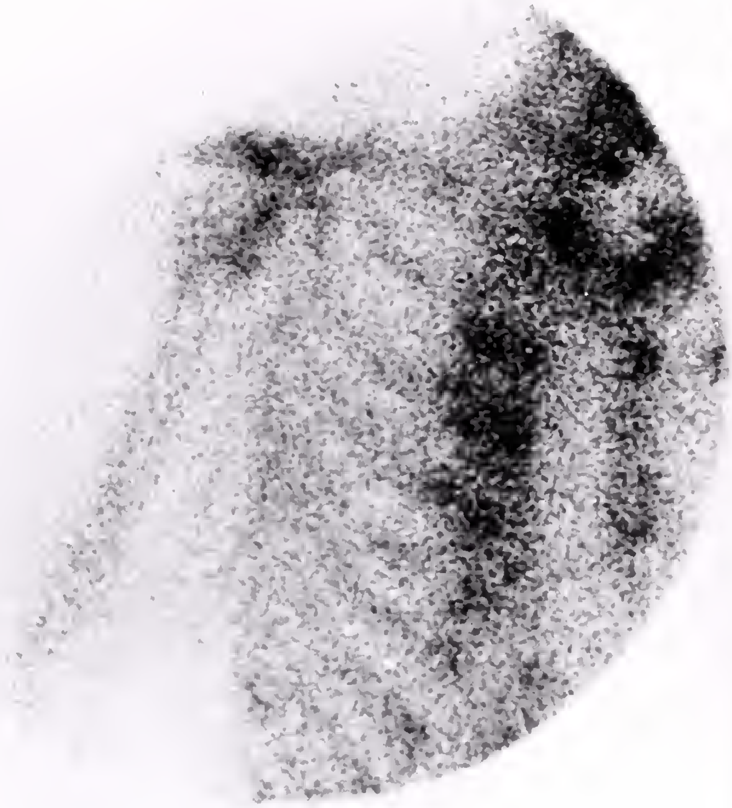
Patient No. 16

Figure 16

Cystic Appearance of Mesosternum
and
Vague Suggestion of Joint Between First and Second and
Third and Fourth Sternebrae

Figure 17

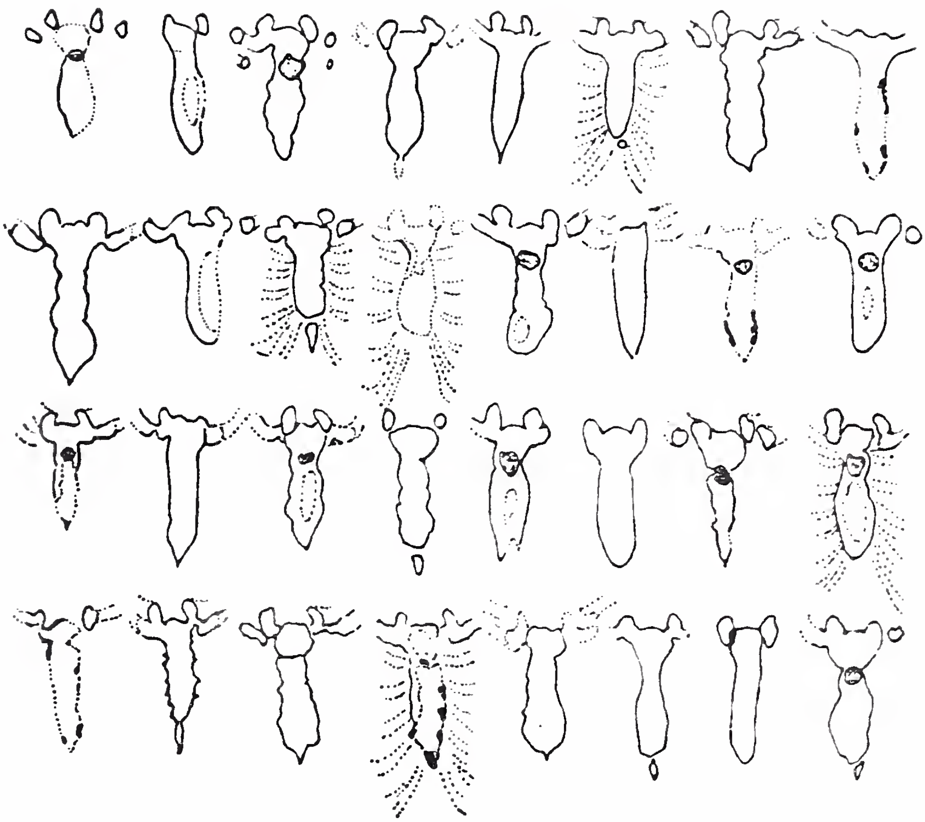
Patient No. 23



A Confusing MSJ

Patient No. 21

Figure 18



(Ono, 1980)

Tracings of the bone scan image of 32 cases selected at random form 330 cancer patients without skeletal metastasis. These tracings illustrate the variability of both the anatomy and the image of the sternum.

Figure 19